Warped Supersymmetric Radius Stabilization[a]

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ABSTRACT

A simple model of extra-dimensional radius stabilization in a supersymmetric Randall-Sundrum model is presented. In our model, we introduce only a bulk hypermultiplet and source terms on each boundary branes. With an appropriate choice of model parameters, we find that the radius can be stabilized by supersymmetric vacuum conditions. Since the radion mass can be much larger than the gravitino mass and the supersymmetry breaking scale, the radius stability is ensured even with the supersymmetry breaking. We find a parameter region where unwanted scalar masses induced by quantum corrections through the bulk hypermultiplet and a bulk gravity multiplet are suppressed and the anomaly mediation contributions dominate.

1. Introduction

Recent attention to the brane world scenario is originally motivated by an alternative solution to the gauge hierarchy problem without supersymmetry (SUSY). There are two well-known scenarios, namely "Large Extra Dimension" [1] and "Warped Extra Dimension" [2]. However, there is an alternative motivation to consider the brane world scenario in the context of SUSY breaking mediation in supergravity (SUGRA). In 4D SUSY phenomenology, SUSY particle spectrum is severely constrained to be almost flavor blind and CP invariant. In gravity mediation scenario, once SUSY is broken in the hidden sector, its breaking is transmitted to the visible sector through the Planck-suppressed SUGRA contact interaction between the hidden and the visible sector:

$$\int d^4\theta c_{ij} \frac{Z^\dagger Z Q_i^\dagger Q_j}{M_4^2} \to c_{ij} m_{3/2}^2 \tilde{Q}_i^\dagger \tilde{Q}_j, \tag{1}$$

where Z is a hidden sector chiral superfield with nonvanishing vacuum expectation value (VEV) of auxiliary field, Q_i is the minimal SUSY standard model (MSSM) chiral superfields of i-th flavor, $\tilde{Q}_i$ is its scalar component, c_{ij} are flavor-dependent constants, and M_4 is a 4D Planck scale. If $F_Z \neq 0$, we obtain soft scalar masses of the order of the gravitino mass $m_{3/2}$ for the scalar partners. The problem is that there is no symmetry reason for $c_{ij} = \delta_{ij}$ in 4D SUGRA, namely $c_{ij} \neq \delta_{ij}$ in general. Therefore, the 4D SUGRA model suffers from the SUSY flavor problem.

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Recently, it was proposed that the direct contact terms such as (1) are naturally suppressed if the visible sector and the hidden sector are separated from each other along the direction of extra spatial dimensions [3,4]. This is because the higher dimensional locality forbids the direct contact terms. In this setup, soft SUSY breaking terms in the visible sector are generated through a superconformal anomaly (anomaly mediation) and the resulting mass spectrum is found to be flavor blind [3,5]. Thus, it is well motivated to consider the SUSY brane world scenario.

In the brane world scenario, there is an important issue called "radius stabilization". For the scenario to be viable, the radius should be stabilized. In the normal brane world scenario, there is no radion potential in SUSY limit since the radion is a modulus. If SUSY is broken, the nontrivial potential is generated, such a potential usually destabilizes the radius. While we have to introduce additional bulk fields to stabilize the radius, these new fields might generate new flavor violating SUSY breaking terms larger than the anomaly mediation contributions [6]. This situation makes a realistic model construction very hard.

2. Model

In this talk, we propose a simple model of extra-dimensional radius stabilization in a SUSY Randall-Sundrum model. Lagrangian of our model [7] is given by

$$\begin{aligned}
\mathcal{L}_5 &= \int d^4\theta \frac{T+T^\dagger}{2} e^{-(T+T^\dagger)\sigma}\left[-6M_5^3 + |H|^2 + |H^c|^2\right]|\phi|^2 \\
&+ \left[\int d^2\theta \phi^3 e^{-3T\sigma} H \left\{\left(-\partial_y + \left(\frac{3}{2}+c\right)T\sigma'\right)H^c + W_b(y)\right\} + \text{h.c.}\right], \qquad (2)\\
&\to \int d^4\theta \left[-3M_5^3(T+T^\dagger)|\omega|^2 + \frac{T+T^\dagger}{2}(|H|^2+|H^c|^2)\right] \\
&\quad + \left[\int d^2\theta \omega H \left\{-\partial_y H^c + \left(c+\frac{1}{2}\right)T\sigma' H^c + \omega W_b\right\} + \text{h.c.}\right], \qquad (3)
\end{aligned}$$

where five dimensional spacetime metric compactified on S^1/Z_2 is given by

$$ds^2 = e^{-2r\sigma(y)}\eta_{\mu\nu}dx^\mu dx^\nu - r^2 dy^2, \ (\mu,\nu = 0,1,2,3) \qquad (4)$$

where r is the radius of the fifth dimension, $0 \le y \le \pi$ is the angle on S^1, and $\sigma(y) = k|y|$ with k being an AdS_5 curvature scale. The prime denotes the differentiation with respect to y, T is a radion chiral multiplet whose real part of scalar component gives the radius r, $\phi = 1 + \theta^2 F_\phi$ is a compensating multiplet, H and H^c are hypermultiplet components in terms of superfield notation in N=1 SUSY in four dimensions, and Z_2 parity for H and H^c are defined as even and odd, respectively. The boundary superpotentials are introduced as $W_b \equiv J_0\delta(y) - J_\pi\delta(y-\pi)$, where $J_{0,\pi}$ are constant source terms on each boundary branes at $y = 0, \pi$. The second form of Lagrangian (3) is obtained by making the field redefinition to simplify our analysis,

$$(H, H^c) \to \frac{1}{\omega}(H, H^c), \quad \omega \equiv \phi e^{-T\sigma}. \qquad (5)$$

It is straightforward to obtain SUSY solutions by solving F-flatness conditions,

$$\begin{aligned} H(y) &= C_H e^{(1/2-c)T\sigma} = 0, \quad H^c(y) \equiv \epsilon(y)\tilde{H}^c(y) = C_{\tilde{H}^c}\epsilon(y)e^{(c+1/2)T\sigma}, \qquad (6)\\ \tilde{H}^c(0) &= \frac{J_0}{2}, \quad \tilde{H}^c(\pi) = \frac{J_\pi}{2}e^{-Tk\pi}, \qquad (7)\end{aligned}$$

where $C_{H,\tilde{H}^c}$ are constants. These solutions give a SUSY vacuum condition of the form

$$0 = J_0 - J_\pi e^{-(3/2+c)Tk\pi}. \qquad (8)$$

Thus, the radius is determined by appropriate values of $J_{0,\pi}$ and the bulk hypermultiplet mass c. This is our main result.

We have seen that the radius is stabilized, then we would like to know the radion mass. To do that, it is useful to describe our model in the form of 4D effective theory. Putting the SUSY classical solutions into our Lagrangian and integrating out the fifth dimensional coordinate, we can obtain 4D effective action. Now it is easy to calculate the radion potential and the radion mass.

$$\begin{aligned} V_{\text{radion}} &= \frac{(1-2c)k}{e^{(1/2-c)(T+T^\dagger)k\pi}-1}\left|J_0 - J_\pi e^{-(c+\frac{3}{2})Tk\pi}\right|^2, \qquad (9)\\ m^2_{\text{radion}} &\sim \frac{(1-2c)}{e^{(1/2-c)(T+T^\dagger)k\pi}-1}\left(\frac{(\frac{3}{2}+c)^2|J_\pi|^2}{3M_5^3}\right)k^2\, e^{-(1/2+c)(T+T^\dagger)k\pi}\Big|_{T=T_0} > 0. \qquad (10)\end{aligned}$$

We can easily find the potential minimum $J_0 - J_\pi e^{-(c+\frac{3}{2})T_0 k\pi} = 0$ from (9), which, of course, agrees with (8). Note that the radion mass squared is always positive, which means that the configuration we found is stable. As an example, if we take $c = 1/2$, $e^{-T_0 k\pi} \sim 10^{-2}$, $J_\pi \sim (0.1 \times M_5)^{3/2}$ and $k \sim 0.1 \times M_5$, we obtain the radion mass,

$$m^2_{\text{radion}} \sim (10^{-5} \times M_4)^2 \gg m^2_{3/2}, F_{\text{hidden}}, \qquad (11)$$

which is much larger than the gravitino mass (~ 10 TeV) in anomaly mediation scenario and the original SUSY breaking F-term scale $F_{\text{hidden}} \sim m_{3/2}M_4$ in a hidden sector. This fact implies that SUSY breaking effects little affect the radion potential, and the radius is not destabilized even in the presence of SUSY breaking. We have checked this expectation by considering SUSY breaking perturbatively. It is explicitly shown that the deviation of the radius from the radius in SUSY limit vanishes up to linear order of SUSY breaking scale.

In our model, we have a hypermultiplet and a gravity multiplet in the bulk. In general, there is a possibility that the hypermultiplet generates the flavor-dependent soft SUSY breaking sfermion masses since a zero mode of the parity even field H can directly couple to both the hidden sector and the visible sector. The gravity multiplet can also couple to the both sectors and generates flavor-blind but tachyonic sfermion mass squareds [8], which might break the standard model gauge group symmetry. It is in general possible that these contributions become larger than the anomaly mediation contributions. We can easily find the parameter region where these contributions to sfermion masses by

the hypermultiplet and the gravity multiplet are strongly suppressed compared to the anomaly mediation spectrum. Therefore, we have no SUSY flavor problem.

3. Summary

In this talk, we have proposed a simple model of extra-dimensional radius stabilization in the SUSY Randall-Sundrum model. With only a bulk hypermultiplet and the source terms on the boundary branes, the radius stabilization has been realized through SUSY vacuum conditions. The radion mass is found to be very large, this radius stabilization is ensured even if the SUSY breaking effects are taken into account. Our model gives a remarkable advantage for model building in the SUSY brane world, since the radius can be stabilized independently of the SUSY breaking and its mediation mechanism. Our model may be applicable to many models. We find a reasonable parameter region where unwanted contributions to scalar mass squared through the bulk multiplets are strongly suppressed.

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5. References

[1] N. Arkani-Hamed, S. Dimopoulos and G. R. Dvali, Phys. Lett. B **429**, 263 (1998) [arXiv:hep-ph/9803315]; I. Antoniadis, N. Arkani-Hamed, S. Dimopoulos and G. R. Dvali, Phys. Lett. B **436**, 257 (1998) [arXiv:hep-ph/9804398].

[2] L. Randall and R. Sundrum, Phys. Rev. Lett. **83**, 3370 (1999) [arXiv:hep-ph/9905221]; Phys. Rev. Lett. **83**, 4690 (1999) [arXiv:hep-th/9906064].

[3] L. Randall and R. Sundrum, Nucl. Phys. B **557**, 79 (1999) [arXiv:hep-th/9810155].

[4] M. A. Luty and R. Sundrum, Phys. Rev. D **62**, 035008 (2000) [arXiv:hep-th/9910202].

[5] G. F. Giudice, M. A. Luty, H. Murayama and R. Rattazzi, JHEP **9812**, 027 (1998) [arXiv:hep-ph/9810442].

[6] M. A. Luty and N. Okada, JHEP **0304**, 050 (2003) [arXiv:hep-th/0209178].

[7] N. Maru and N. Okada, Phys. Rev. D **70**, 025002 (2004) [arXiv:hep-th/0312148].

[8] T. Gherghetta and A. Riotto, Nucl. Phys. B **623**, 97 (2002) [arXiv:hep-th/0110022]; I. L. Buchbinder, S. J. J. Gates, H. S. J. Goh, W. D. . Linch, M. A. Luty, S. P. Ng and J. Phillips, Phys. Rev. D **70**, 025008 (2004) [arXiv:hep-th/0305169]; R. Rattazzi, C. A. Scrucca and A. Strumia, Nucl. Phys. B **674**, 171 (2003) [arXiv:hep-th/0305184].